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ASTROS ENHANCEMENTS

FINAL REPORT

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ASTROS (Automated STRuctural Optimization System) is a computer program for the multidisciplinary design and analysis of aerospace structures. ASTROS combines mathematical optimization algorithms with traditional structural analysis disciplines such as static forces, normal modes, static aeroelasticity, and automated preliminary design of an aircraft structure. This report is a complete user's manual that documents the many features of ASTROS through version 12 of the software package. It also provides information on system architecture and other topics of interest. This report is Volume 3 of a set; Volume 1 (WL-TR-93-3025) is the user's manual.

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FOREWORD

This program, contract F33615-87-C-3216, Project 2401 entitled *ASTROS Enhancements*, had four specific goals:

- To enhance the Automated Structural Optimization System (ASTROS) by providing new features
- To improve those already in place
- To maintain the system
- To determine the methods of releasing the system to public users.

The program included six broad task categories:

- Finite Element Library Addition
- Aeroelastic Analysis Improvements
- Structural Optimization Methods
- Computational Efficiency Improvements
- Quality Assurance
- Post-Processor Interfaces

These tasks were performed by over the period May 1987-May 1994 by Universal Analytics, Inc. and their subcontractor, the Northrop Corp.

Please note that the three volumes of User documentation:

- ASTROS User's Manual
- ASTROS Programmer's Manaual
- ASTROS Theoretical Manual

are incorporated into this document by reference. There is no attempt to cover technical details found in those documents (more than 1500 pages) nor in the 1000 pages of R&D Status Reports that have been submitted over the life of this effort. Rather, the following sections of this report summarize each of the work items performed in accomplishing the contract tasks and, where appropriate, present some highlights of the development. This report also reviews the history of the program through Semi-Annual Reviews, Contract Data Requirements and ASTROS system releases.

TASK 1. FINITE ELEMENT LIBRARY

Under this task, UAI was to perform three subtasks. These are:

Contract Ref.	TASK NUMBER AND DESCRIPTION	Effective Date
3.1	1.0 Finite Element Library	22SEP87
3.1.1	1.1 Formulation of a TRIA3 Element	22SEP87
3.1.2	1.2 Rigid Elements	SPIIN P00007 20NOV89
3.1.5	1.5 Automatic SPC Generator	SPIIN P00021 14SEP92

Each of these are described in the following sections.

1.1 FORMULATION OF A TRIA3 ELEMENT

The purpose of this task was to develop a three-noded isoparametric plate and shell finite element called the TRIA3. This element is the companion to the quadrilateral QUAD4 element developed by UAI under the original ASTROS contract. The TRIA3 was to support all of the QUAD4 features including variable bending propoerties and laminated composites.

In 2Q88 and 3Q88, UAI developed the theoretical specification of the TRIA3 element. This specification was completed during 4Q88 and implementation began. The formal specification was included in the R&D Status Report for that period.

During 1Q89 and 2Q89 UAI completed the coding, implementation, testing and installation of the new TRIA3 finite element. While performing this task, various minor problems in the QUAD4 element were also corrected. The results of the element accuracy tests for both elements are presented in Table 1. These results indicate that the quality of the new ASTROS elements rivals that found in the commercially available NASTRAN systems. The grade scores are those defined in the paper "A Proposed Set of Problems to Test Finite Element Accuracy" by MacNeal and Harder (*Finite Elements in Analysis and Design*, No. 1, North-Holland, Amsterdam, 1985).

1.2 RIGID ELEMENTS

The purpose of this task, added under the contract modification of 20 November 1989, was to implement the rigid elements RBAR, RROD, RBE1 and RBE2 into ASTROS in order to simplify the definition of multipoint constraints which now require the laborious preparation of MPC data entries. This task began in 4Q89 with the development of the executive and user interfaces to these features. By 1Q95, these elements had been installed into the ASTROS development system, and they were undergoing full integrated testing.

Highlights of the rigid element development included detailed error checking which improves on that found in the test comparator, MSC/NASTRAN. Unlike NASTRAN, the ASTROS rigid elements may be selected using the MPC parameter on the BOUNDARY Solution Control command. This has generalized the rigid elements in the same manner as MPC equations — they may be changed from boundary condition to boundary condition. This feature is imperative in the multidisciplinary design process.

TEST	ELEMENT LOADING		ELEMENT SHAPE	QUAD4	TRIA3
	IN-PLANE	OUT-OF-PLANE			
1. PATCH TEST	■	■	IRREGULAR	A	A
2. STRAIGHT BEAM, EXTENSION	■		ALL	A	A
3. STRAIGHT BEAM, BENDING	■		REGULAR	B	F
4. STRAIGHT BEAM, BENDING	■		IRREGULAR	F	F
5. STRAIGHT BEAM, BENDING		■	REGULAR	A	B
6. STRAIGHT BEAM, BENDING		■	IRREGULAR	A	B
7. STRAIGHT BEAM, TWIST	■		ALL	B	F
8. CURVED BEAM	■		REGULAR	C	F
9. CURVED BEAM		■	REGULAR	B	B
10. TWISTED BEAM	■	■	REGULAR	A	B
11. RECTANGULAR PLATE		■	REGULAR	A	B
12. SCORDELIS-LO ROOF	■	■	REGULAR	B	D
13. SPHERICAL SHELL	■	■	REGULAR	A	B
14. THICK WALLED CYLINDER	■		REGULAR	B	A

UAI completed comprehensive testing in 2Q95, and the new elements were made available in the ASTROS Version 6 release.

1.3 AUTOMATIC SPC GENERATOR

Task 1.5 was added under the contract modification of 14 September 1992. The purpose of this task was to develop an Automatic SPC generator comparable to those found in commercial finite element products. This feature is a user convenience which simplifies modeling. Design work began in 1Q93. Then, at the request of COTR, work was accelerated to assist the Government in providing more features for aerospace companies using ASTROS for the HSCT program. The implementation and testing were completed during 2Q93, and the feature was delivered on 1 October 1993 as part of the ASTROS Version 10.5 interim system.

TASK 2. AERODYNAMICS

Under this task, UAI was to perform 10 subtasks. These are:

Contract Ref.	TASK NUMBER AND DESCRIPTION	Effective Date
3.2.1	2.1 Aerodynamic Influence Coefficients for Bodies	22SEP87
3.2.2	2.2 Eliminating Fixed Size Arrays	22SEP87
3.2.3	2.3 Nonplanar Boundary Condition Option	22SEP87
3.2.4	2.4 Control Surface with Inset Tabs	22SEP87
3.2.5	2.5 Control Surface Effectiveness	22SEP87
3.2.6	2.6 Linear Spline	22SEP87
3.2.7	2.7 New Aeroelastic Constraints — Roll Rate Constraint, Pitch Rate Constraint, Control Surface Constraint	SPIIN P00007 20NOV89
3.2.11	2.11 Fast Fourier Transform	SPIIN P00021 14SEP92

Each of these are described in the following sections.

2.1 BASIC AERODYNAMIC ENHANCEMENTS

Under the original enhancements contract, five new features were to be developed:

- 2.1 Aerodynamic Influence Coefficients for Bodies
- 2.2 Eliminating Fixed Size Arrays
- 2.3 Nonplanar Boundary Condition Option
- 2.4 Control Surface with Inset Tabs
- 2.5 Control Surface Effectiveness

Work on these tasks commenced in 3Q88. Two work items were performed: the development of the Functional and Theoretical Specifications for the new enhancements, and an outline of the approach to be used in removing the fixed-size arrays from the USSAERO module of ASTROS.

During 4Q88, the work on the aerodynamics enhancements focussed on the elimination of the fixed-size arrays in the USSAERO-based steady aerodynamics module. The analysis of the source code showed that 32 common blocks, each with several fixed dimension arrays, needed to be replaced by the ASTROS dynamic memory utilities. The task of replacing these arrays was not as straight-forward as originally supposed because the data needed to determine the amount of memory to allocate was not always available. This resulted in the coding of two new routines that compute the dimensioning data directly from the input data stream prior to performing the actual geometry and panelling operations.

During 1Q89, the removal of the fixed-size arrays in the USSAERO-based steady aerodynamics module was completed. Several test cases were used to demonstrate that the resulting code was functioning correctly. The new code was made available in the Version 4 ASTROS system. Additionally, the functional specifications and most of the theoretical specifications for the re-

maining aerodynamic enhancements have been completed. An extensive study of the ASTROS aeroelastic features has led to a development plan which adds all new capabilities and, at the same time, makes all features more consistent.

During 2Q89 and 3Q89 all of the aeroelastic enhancements, with the exception of the nonplanar boundary condition option, were completed and tested. Northrop experienced several difficulties in implementing the nonplanar boundary condition option. The principal difficulty encountered was that the nonplanar option in the version of USSAERO-C that Northrop used as a reusable code resource was in error. This was illustrated by using both the planar and nonplanar options for a thin airfoil. Although the results of these two cases should have been comparable, there were significant differences.

During 4Q89, it was determined that ASTROS matched the nonplanar solution of UASSAERO-C thus ending this task. All of the aerodynamic features were made available to the public in Version 5.0 of ASTROS.

2.2 LINEAR SPLINE

During 2Q89, the linear SPLINE1 element of COSMIC NASTRAN was partially incorporated into the ASTROS spline module. Completion required the addition of the ASTROS steady aerodynamic macroelements which were not part of the original COSMIC NASTRAN. These features were completed, and during 3Q89, the spline implementation was completed.

2.3 NEW AEROELASTIC CONSTRAINTS

The new contract modifications of 20 November 1989 added three new work items related to the ASTROS aerodynamics capability. These were:

- Roll rate constraint definition and sensitivities
- Pitch rate constraint definition and sensitivities
- Control surface deflection constraint definition and sensitivities

UAI's subcontractor, Northrop Corp., developed the theoretical and functional specifications for these features during 1Q90. During 2Q90, Northrop completed the implementation of these features. Two new constraint definition Bulk Data entries were added to ASTROS which allow the user to constrain any number of aerodynamic parameters and/or stability coefficients. This provided all of the capabilities specified above in a manner fully consistent with the other ASTROS aerodynamic constraints.

The first new constraint is defined by DCONTRM data. It allows the user to place upper and/or lower bound constraints on any of the trim variables when performing and ASTROS steady aeroelastic trim analysis. Thus, the user can constrain any control surface deflection, trim parameter, (angle of attack, yaw angle, roll rate, pitch rate, yaw rate) and/or any component of the structural acceleration at the support point. The actual number of parameters that can be constrained by DCONTRM is unlimited, since the user may define an unlimited number of control surfaces.

The second type of constraint is defined by DCONSCF Bulk Data. It allows the user to place upper and/or lower bound constraints on any or all of the flexible stability derivatives at the reference grid point. When using this feature, the user is actually defining a limiting value for the FLEXIBLE quantities in the TRIM table.

These two new constraints, combined with those already available, provide a comprehensive suite of constraints on the aeroelastic performance of the vehicle. Two possible applications of these new features are to optimize for a particular level of longitudinal stability (quantified as the flexibility stability coefficient for pitch moment due to angle of attack), and/or to optimize for a particular positive, zero, or negative control surface effectiveness. This latter feature is a generalization of the current aileron effectiveness constraint but makes no assumptions about the axis of interest.

2.4 FFT WITH RANDOM INPUT

Under the contract modification of 14 September 1992, a new task was added to the effort to implement a Fast Fourier Transform algorithm to facilitate time and/or frequency domain analysis with random inputs. The first part of this task required a comprehensive evaluation of the existing software. A number of test cases were developed for both time and frequency domain analyses. These were executed and uncovered a number of errors which primarily related to the communication between the FFT subroutines and the MAPOL sequence.

While the FFT algorithm itself was functioning properly, these errors in the generation of time loadings and frequency lists, led to failure of the test cases. Additionally, there were errors in the handling of frequency response solution vectors both prior to and after the inverse FFT was applied. All of these errors were identified and corrected. The final status of this capability shows that it functions properly under certain circumstances, but there are still problems that require future correction.

TASK 3. OPTIMIZATION

Under this task, UAI was to perform six subtasks. These are:

Contract Ref.	TASK NUMBER AND DESCRIPTION	Effective Date
3.3	3.0 Optimality Criterion Methods	22SEP87
3.3.1	3.1 Generalized Stiffness Constraint	SPIIN P00011 28SEP90
3.3.2	3.2 Stress/Strain Constraints	SPIIN P00011 28SEP90
3.3.3	3.3 Bending Element Optimization	SPIIN P00021 14SEP92
3.3.4	3.4 Buckling Optimization	SPIIN P00021 14SEP92
3.3.5	3.5 User Defined Objective Function, Constraint and Sensitivity	SPIIN P00021 14SEP92
3.3.6	3.6 Composite Laminate Constraints	SPIIN P00021 14SEP92

Each of these are described in the following sections.

3.1 OPTIMALITY CRITERION METHODS

The purpose of this task was to implement government-furnished software which performs structural optimization based on the Optimality Criterion Methods. This new method was intended to supplement the original optimization methodology based on Mathematical Programming.

This task proved to be the most problematic of those performed under this effort. Under the original contract, UAI was to design, code, and test Optimality Criteria methods within ASTROS. The contract modification dated 28 September 1990 then changed the task significantly. Under the modification, UAI became responsible for installing and testing optimization software provided as GFE by the Air Force. While a portion of this software was transmitted to UAI by COTR on 17 November 1989, it was not sufficient to perform the required implementation activities. The schedule for this task was thus deferred until the arrival of all required software.

UAI received the GFE Optimality Criteria software in late July 1990 and transmitted a copy to Northrop in early August. Northrop studied the software documentation and source code and designed an documented and interface to allow its integration into ASTROS. This interface was then coded and tested. Northrop was unable to achieve convergence for any of the standard ASTROS Application Manual test problems. Consultation with the Air Force software developers indicated that the convergence problem was due to the new GFE software, not the baseline ASTROS system. The code developed to interface the GFE software was sent to the Air Force to assist them in developing a working algorithm. Further work has been halted pending the delivery of an upgraded version of the GFE software from WRDC. This difficulty again required modifications to the Program Schedule.

During 4Q90, Northrop reorganized the main driver routine, called VANGO, to make it fully compatible with ASTROS, and modified the standard MAPOL sequence to use the new optimal-

ity criteria method within ASTROS, either alone or in combination with the other optimization options. Solution control was modified to allow user control of this feature. All other work was suspended pending the delivery of an upgraded version of the GFE software from the Government.

In 2Q94, COTR indicated that upgrades to the GFE Optimality Criteria software would not be forthcoming. Thus, Task 3.0 was completed per the implementation described above.

3.2 GENERALIZED STIFFNESS CONSTRAINT

The purpose of this task was to implement a generalized stiffness constraint, provided by the Government, in ASTROS. The generalized stiffness constraint is intended to be used with the optimality criterion methods described in the previous section. The intent of this feature is to improve performance by reducing the number of stress constraints used during optimization. UAI completed the preliminary implementation of this constraint during 1Q92. The technique did not yield acceptable results, and interim test data was delivered to the Government for evaluation. Work has halted pending this investigation. While the basic method employed would have resulted in potential savings during optimization, the stability of the technique proved unacceptable and further work was abandoned.

3.3 STRESS/STRAIN CONSTRAINTS

The purpose of this task was to improve the methods used for specifying stress and strain constraints in ASTROS. The initial implementation, which followed that used by a commercial vendor, proved to be ambiguous. This occurred because all material allowables have been defined on a MATi Bulk Data entry. The tension, compression ands shear allowables are thus applied to either the stresses or the strains, but not both. There was no alternate method which allowed constraints to be applied both types of responses. The sections below outline the modifications that UAI made to remove this restriction. Basically, separate constraints were allowed for each response type, and two forms of strain constraints were implemented.

Two additional important extensions were also made. Firstly, the constraints were allowed to be selectable by analysis case. This allows a design to satisfy multiple sets of allowables which represent, for example, damage or hot/wet environments. Secondly, the constraints may be selected by either element identification number or by element property identification number. This feature greatly simplifies input for modest numbers of constraints. The original method only supported the definition of these constraints by material identification number.

The original Von Mises stress constraint and Tsai-Wu stress constraint were modified for these changes. Additionally, two new Bulk Data entries were added to ASTROS to implement both the principal strain allowables, favored by Northrop, and the fiber and transverse strain allowables favored by General Dynamics. In the first case, these data are defined by the strain limits for tension, compression, and shear, respectively. In the second, they are defined by the tension and compression strain limits in both the fiber direction and the transverse direction.

All of the improved methods used for specifying stress and strain constraints in ASTROS were included for release in Version 8.0.

3.4 BENDING ELEMENT SENSITIVITY

The purpose of this task was to expand the ASTROS optimization capability to bending elements. To do this required a significant reengineering of the software. ASTROS originally assumed that all design variables would be result in factorable mass and stiffness matrices. That is, that the design variables, such as membrane thickness and bar cross-sectional area could be factored out of the element stiffness matrices. As a result, design sensitivities were available analytically. Under this task, it was necessary to remove this restriction and compute sensitivities of nonlinear design variables, such as plate bending thicking, semi-analytically using finite difference methods.

Preliminary design work on this major new capability was begun in 4Q92. The level of effort was reduced over the next several quarters due to funding allocation delays. However, by 2Q93 the comprehensive preliminary design document was completed and delivered as part of the R&D Status Report for that period.

Late funding allocations then reduced the level of effort until 2Q94 when the initial implementation was made. Comprehensive unit and integrated testing was performed. Numerous errors were detected which required significant labor to analyze and correct. This occurred because of the large number of major infrastructural changes made to ASTROS to support this capability. These changes "touched" so many areas of the system that many test cases had to be formulated and executed to insure that the new capability functioned propoerly, and, that it had not disabled any other parts of the program.

UAI added an important additional work item required under this task to handle design variable coupling for the BAR element. The initial ASTROS design assumed that there was an exponential relationship between the cross-sectional area and moments of inertia for such elements. This crude approximation allowed the computation of analytical sensitivities in the original design but was found to be totally inadequate in modeling design degrees of freedom. UAI suggested, and COTR agreed, that the "PBAR1" technique developed by UAI for other purposes would solve this problem. The PBAR1 approach allows users to define the actual cross-sectional geometry of elements based on geometric parameters. These parameters, which then become the physical design variables, can be used to compute the dependent BAR parameters — area and moments of inertia. As a result, all of the design degrees of freedom are correctly modeled and the stiffness, mass, and element responses are consistent, and they can be handled during the design process.

The implementation of the PBAR1 was also significantly more difficult than originally thought. An original design axiom of ASTROS was that each finite element would have only a single design variable. Because the PBAR1 allows elements to have from 1 to 10 design variables, this axiom was broken. To change the old computational paradigm required the modification of many more subroutines and data structures than originally anticipated.

During the 3Q94, the processing of design variable coupling for the BAR element was completed. Comprehensive unit and integrated testing have been performed with excellent results. A small number of tests relating to the PBAR1 remained. All further testing and error correction was performed during 4Q94 and 1Q95, and the completed capability released in ASTROS version 12.0.

3.5 BUCKLING OPTIMIZATION

The purpose of this task, added under the contract modification of 14 September 1992, was to develop local buckling constraints for stiffened panels. Work began in 2Q93, when the preliminary design specifications were prepared. The task was to proceed in three phases as described below.

The first phase was the implementation of the unstiffened panel buckling. This was completed during 3Q93 and 4Q93, and preliminary testing showed good results.

The second and third phases were implemented and tested during 4Q93. The second phase was the installation of the Euler column buckling for ROD and BAR elements. This procedure was similar to that already implemented for the unstiffened panel buckling, i.e. a single control element is selected and its load applied to the "logical" beams defined by the user. Inertia linking during the design is accomplished using the usual power law as:

$$I = r \cdot A^{\alpha}$$

A test case was run to verify the capability. The problem selected was the 25 bar truss as defined in the MSC Design Optimization Handbook. The ASTROS results were very similar, but the members that are resized to their minimum size were slightly larger in ASTROS. This is because of the nonlinearity of the eigenvalue which is only being approximated in ASTROS, while MSC/NASTRAN is using function evaluation to obtain a higher-order approximation to the correct nonlinear behavior.

The third phase was the implementation of the panel buckling capabilty for PSHELL properties. This was accomplished by assuming a relationship between the bending, membrane and transverse shear properties of the element. The feature was verified by solving the ICW model.

The completed capability, including all of the options described above, was delivered in Version 11.0 ASTROS.

3.6 USER DEFINED OBJECTIVE FUNCTION, CONSTRAINT AND SENSITIVITY

The purpose of this task, added under the contract modification of 14 September 1992, was to allow arbitrary functional forms for design constraints, and the objective function, within ASTROS.

The initial design of this capability was begun in 2Q93. The design was completed in 3Q93 and presented in the R&D Status Report for that period. During 4Q93 the language compiler needed to interpret the user functions, and to compute the necessary derivatives for sensitivity analysis were implemented. The implementation of the capability into ASTROS proved to be more time consuming than originally estimated due to the major infrastructural changes required to the ASTROS software architecture.

Specifically, in order to evaluate the functions and their corresponding derivatives, it was necessary to gather numerical values and terms from numerous areas within ASTROS. This resulted in the modification of many modules. The basic implementation of this major new capability was completed in 3Q94 and comprehensive unit and integrated testing began. The testing was also significant because of the pervasiveness of the major changes made to ASTROS to support this capability.

A hiatus of several months occurred due to lateness of funding authorization. Additionally, this task required more human resources than originally estimated. This is not surprising given the

high technological risk associated with this task. The capability was completed during 4Q94 and 1Q95 and was delivered with the final Version 12.0 ASTROS system.

3.7 COMPOSITE LAMINATE CONSTRAINTS

The purpose of this task, added under the contract modification of 14 September 1992, was the development and installation of manufacturing constraints for composite materials. A new set of design constraints were defined to handle the common composite manufacturing requirements that are applied during the design of structures using composite laminates. These constraints are on: the ply minimum gauge; the laminate minimum gauge; and the percentage of the laminate that is made up of a ply. Together with the use of design variable linking and side constraints on both the local and global design variables, these constraints allow the user to ensure that the optimization process will generate a thickness distribution that is at least reasonably close to a manufacturable laminate. Of course, the restriction of a continuous design variable approximation to the discrete layer thicknesses is still present.

The new constraints are defined using the **DCONPMN**, **DCONLMN** and **DCONLAM** Bulk Data entries to define ply minimum gauge, laminate minimum gauge and laminate composition constraints, respectively. The laminate composition constraints allow the specification of an upper or lower bound on the percentage of a *laminate* thickness that is composed of a particular *ply* thickness. The other two constraints are self-evident.

All three constraints share common definitions of the *ply* and the *laminate*, which are worthy of some discussion. A *ply* consists of one or more layers whose ***summed*** thicknesses will constitute the ply thickness. Similarly, a *laminate* is one or more layers whose ***summed*** thicknesses will constitute the total laminate thickness. A "layer" is one **MID/THETA/T** combination on either a **PCOMP, PCOMP1** or **PCOMP2** entry. The principal difference between a *ply* and a *laminate* is that the defaults are set up to allow simple input when a ply is a single layer and when a laminate consists of all layers.

The generality of the ply and the laminate definitions provides for the generality of the typical composite composition constraints. For example, there are usually both lower and upper bound fractions of the laminate thickness for each distinct fiber orientation. These orientations may be (and usually are) separated into noncontiguous layers on the **PCOMP** entry. Therefore, the ply definition needs to be all layers with the same orientation and not just a single layer. For sandwich composites with composite face sheets, each face sheet independently has the manufacturing composition constraint imposed and the core thickness and the other face sheet are not desired in the definition of the laminate thickness. All these scenarios are accommodated in the ASTROS constraint definitions.

Under certain definitions of ply or laminate minimum gauge, the **DCONPMN** or **DCONLMN** are redundant with the side constraint on the local design variable. This will be the case *if* the *ply* or *laminate* consists of only one layer. The installation of these constraints into ASTROS accounts for this circumstance by comparing the minimum gauge against the **TMIN** field of the associated connectivity entry if **SHAPE** linked ***or*** against the computed **TMIN** = (**VMIN***initial value) if physically linked. The most critical gauge limit among all **DCONPMN, DCONLMN** and **TMIN** values will be used to update the side constraint value and the **DCONPMN** and/or **DCONLMN** will be disabled (since they are now redundant). A table of these actions is printed to the output file to inform the user that ASTROS has replaced some user-defined constraints.

In defining the composite manufacturing constraints, a **PLYLIST** Bulk Data entry was developed to define the plies that compose the *ply* or *laminate*. With the creation of this input entry, it

was decided to make use of it in all aspects of the design model. The **DESVARP** and **DESVARS** entries were therefore modified to reference **PLYLIST** sets instead of the **SET1** entries that were originally used. Updating older models involves changing the name **SET1** to **PLYLIST** for all **SET1** entries that are ply lists referenced by **DESVARP** or **DESVARS**. The input format is otherwise unchanged.

Finally, the **DCONTHK** entry was augmented with a **DCONTH2** entry. Functionally, it is the same as the **DCONTHK** except that it allows the selection of thickness constraints at the layer-level rather than the element-level. Under **DCONTHK** entries, the thickness constraints of all layers of a composite are retained as active. Under **DCONTH2**, only those layers that are called out are retained. This avoids the problems that can occur with many redundant constraints (same constraint value and identical sensitivities). This problem occurs frequently when the design variable linking is enforcing a symmetry condition: each layer thickness is treated as an independent constraint when, in fact, the layers across the plane of symmetry are identical constraints.

TASK 4. COMPUTATIONAL EFFICIENCY

Under this task, UAI was to perform six subtasks. These are:

Contract Ref.	TASK NUMBER AND DESCRIPTION	Effective Date
3.4.1	4.1 Timing Analysis	22SEP87
3.4.2	4.2 Eigenextraction Methods	22SEP87
3.4.2.1	4.2.1 Modified Givens Method	22SEP87
3.4.2.2	4.2.2 Unsymmetric Matrix Techniques	22SEP87
3.4.2.3	4.2.3 Inverse Power Eigenextraction Method Improvements	22SEP87
3.4.2.4	4.2.4 FEER Eigenvalue Analysis Routine	SPIIN P00021 14SEP92
3.4.3	4.3 Grid Point Sequencer	SPIIN P00011 28SEP90
3.4.4	4.4 Cray Single Precision Port	SPIIN P00021 14SEP92

Each of these are described in the following sections.

4.1 TIMING ANALYSIS

The purpose of this task was to determine the manner in which CPU resources are used within ASTROS and to then improve its performance. During 2Q88, UAI prepared 63 test problems that had been developed under the original ASTROS development contract. These problems formed an initial baseline for timing analysis.

The problems were then executed using a *coverage analysis tool* that determines the number of times lines of code are executed within a subroutine. The first set of results showed that the code coverage of the 63 test problems was not adequate for insuring the quality of ASTROS. The development of th formal test specification plan was based on these results.

During 3Q88, UAI defined and documented the Performance Test Problem Library (PTPL). This library contained 15 problems that cover all of the analytical and design capabilities of ASTROS. This resulted in the ***Timing Analysis Problem Selection Report*** (CLIN 0001, CDRL Sequence No. 9) which was delivered to COTR on 2 September 1988.

The problems defined in the Timing Analysis Selection Report were then developed.The test case design goal was to develop problems which require 1-2 hours of CPU time. The completion of some of these test cases required the correction of several outstanding SPRs and the inclusion of the aerodynamic enhancements also being performed (See Task 2 above).

One major performance improvement was made to the unsymmetric decomposition module which comes into play when solving problems that result when unsymmetric aerodynmamic terms are added to the stiffness matrix. A problem that previous ran for 12 hours (the Northrop HALE design) was reduced to 3 hours by correcting a misunderstanding in the algorithm as converted from NASTRAN.

During 1Q89, the development and execution of the problems defined in the Timing Analysis Selection Report has been completed. The table below indicates the status of this test problem library at that point in the effort.

Test Case	CPU	Test Case	CPU
PTSTAT01	0:21	PTSARO02	0:31
PTSTAT02	0:56	PTUSAR01	1:14
PTMODE01	1:38	PTUSAR02	1:34
PTMODE02	2:22	PTGUST01	0:40
PTMODE03	0:38	PTBLST01	0:25
PTTRAN01	1:21	PTDESN01	1:01
PTTRAN02	1:11	PTDESN02	2:33
PTFREQ01	2:18	PTDESN03	1:27
PTFREQ02	1:18	PTDESN04	2:55
PTSARO01	2:16		

The test case design goal was to develop problems which require 1-2 hours of CPU time. By 2Q89, several areas of potential performance improvement had been identified and were being pursued.

UAI then delivered the Performance Test Problem library to the COTR and requested that the test cases be executed using both ASTROS and COSMIC NASTRAN on the same host computer. This request has been met and results were delivered to UAI in the second week of September 1989. The results were then evaluated and a performance improvement plan formulated.

During 4Q89, UAI made substantial performance gains in the PTPL. The most significant contribution to these gains was the activation of the different methods of performing the computationally intense matrix multiplication operations. This required writing a new module, TIMTST, which has been installed into the SYSGEN utility.

This new module performs a number of CADDB operations which determine the CPU requirements for packing and unpacking matrices of the different numeric types: real, single precision; real, double precision; complex, single precision; and complex, double precision. Not only numeric types were considered, but also the density of nonzero terms in the matrices. The module has been made a permanent part of the SYSGEN utility, and it will automatically determine timing parameters for any ASTROS host computer. The fifteen special timing constants are then placed on the system database by SYSGEN in an unstructured entity called TIMCONST.

Once the timing constants were available, the MPYAD module was extended to use these constants. Testing was performed for all of the available MPYAD methods. Numerous errors were uncovered in this code, which was previously not exercised. Many errors were corrected and all methods unit tested. The corrected code was then installed into the development system and the

QA testing performed successfully. The significant performance improvements achieved are evidenced in the following table.

Test Case	ASTROS CPU		Test Case	ASTROS CPU	
	Version 4	Version 5-		Version 4	Version 5-
PTSTAT01	0:18	0:18	PTSARO02	0:29	0:31
PTSTAT02	0:36	0:22	PTUSAR01	2:31	1:13
PTMODE01	1:48	0:57	PTUSAR02	2:57	1:34
PTMODE02	7:42	2:57	PTGUST01	0:55	1:01
PTMODE03	0:21	0:21	PTBLST01	0:52	0:24
PTTRAN01	1:21	0:21	PTDESN01	0:52	0:33
PTTRAN02	0:59	0:52	PTDESN02	1:49	0:41
PTFREQ01	2:18	2:17	PTDESN03	1:44	0:52
PTFREQ02	0:55	0:45	PTDESN04	3:25	1:21
PTSARO01	2:14	1:30	TOTAL	34:06	18:50

The table indicates that the full PTPL speedup is 1.8. Even more importantly, the design test problems which are of maximum importance, have a speedup of 2.3. UAI noted that the major impediment to having ASTROS perform at levels comparable to commercially available finite element systems is the lack of a grid point sequencer, such as the BANDIT code available in COSMIC NASTRAN, which is built into the system. It was noted that without this feature, further ***significant*** performance improvements would not be possible.

At the ASTROS semiannual review of 26 July 1990, the ASTROS Applications contractor, General Dynamics, reported long running times for large problems. This was traced to the unsymmetric decomposition module, DECOMP, and the companion forward-backward substitution module GFBS. Both were originally adapted from COSMIC NASTRAN for ASTROS. UAI discovered a number of severe inefficiencies in this code. It was believed that these inefficiencies were present because the NASTRAN system makes very little use of these modules. On the other hand, their necessity when performing aerodynamic design made them crucial software components of ASTROS. UAI spent significant effort in studying this code in order to improve its performance. Initial studies indicated that the unsymmetric cases runs 10-20 times slower than the same size symmetric solutions. During 4Q90, UAI made substantial modifications to the unsymmetric decomposition modules DECOMP and GFBS. UAI spent significant effort improving the performance of the module because, this code, taken from COSMIC NASTRAN, was very old and complex. Nonetheless, UAI was able to achieve a 2-1 speedup of these modules.

4.2 EIGENVALUE EXTRACTION METHODS

Under this task, there were four distinct work items:

- Modified Givens Method
- Unsymmetric Matrix Techniques
- Inverse Power Eigenextraction Method Improvements
- FEER Eigenvalue Analysis Routine

Each of these is described below.

4.2.1 Modified Given Method

UAI designed and implemented the ***Modified Givens*** method into ASTROS during 1Q89. This method allows for the solution of problems with singular mass matrices by performing appropriate transformations on the eigenvalues.

4.2.2 Unsymmetric Matrix Techniques

Beginning in 3Q89, UAI addressed the issues of unsymmetric and complex eigenextraction. The goals were to improve the ***Complex Eigenextraction*** module, and to evaluate the EISPACK eigenextraction library for implementation into ASTROS. UAI began with the COSMIC NASTRAN complex eigenvalue routine, CEAD, and converted it to function properly for both single and double precision arithmetic. The EISPACK (LICEPACK) subroutines for solving complex eigenproblems by the ***Upper Hessenburg*** method were then installed into this module and converted to function in double precision. The module was then tested in the stand-alone mode. Results of the testing were identical to those obtained with NASTRAN.

After a brief deferral of work to concentrate efforts on error correction and performance improvement prior to the release of ASTROS Version 5, work on the complex eigenvalue routine, CEAD, was reinitiated in 1Q90, and the implementation and testing of this module in ASTROS was completed. Eight test cases used by NASTRAN were executed in ASTROS using direct matrix input. These test cases resulted in the same answers as NASTRAN. Additionally, this module was significantly improved over the original NASTRAN code used as a software resource. Many errors were corrected, the new Upper Hessenberg method from the well-known EISPACK/LICEPACK library was installed, and full support for single and double precision computation was provided.

The complex eigenvalue routine was then installed, and released, in ASTROS Version 6.

4.2.3 Inverse Power Improvements

Beginning in 1Q89, UAI corrected the previously nonfunctional ***Inverse Power*** eigenvalue extraction method. This method is used to extract a small number of frequencies from a large model. It is therefore useful in reducing the cost of large multidisciplinary design problems. Additionally, UAI has improved this method to perform the ***Sturm Sequence Checks*** (SINV) which improve the reliability of the method by insuring that all eigenvalues within the specified range have been found.

The charts below presents the results of all current ASTROS eigenmethods for a simple test problem. The problem is a cantilever beam of length 300 units which is modelled with BAR elements. Test 1 divided the beam into 200 segments which resulted in a problem size of 200 degrees-of-freedom. For Test 2, the number of segments was increased to create 3000 degrees-of-

freedom. The Givens and Modified Givens runs for Test 2 used static condensation to reduce the problem to 200 degrees-of-freedom prior to solution. The first five axial vibration modes are computed using each of the methods. The results, compared with the theoretical values, and the ASTROS CPU time for each method, are given in the table below. Note that the results are in excellent agreement.

TEST 1: 200 DEGREES-OF-FREEDOM					
MODE NUMBER	Eigenvalues, Hz				
	THEORY	GIVENS	MODIFIED GIVENS	SINV	GDR
1	2.74	2.74	2.74	2.74	2.74
2	24.7	24.7	24.7	24.7	24.7
3	68.5	68.5	68.5	68.5	68.5
4	134.3	134.3	134.3	134.3	134.3
5	222.1	222.0	222.0	222.0	222.0
CPU (Sec)	N/A	69	133	229	91

TEST 2: 3000 DEGREES-OF-FREEDOM					
MODE NUMBER	Eigenvalues, Hz				
	THEORY	GIVENS	MODIFIED GIVENS	SINV	GDR
1	2.74	2.74	2.74	2.74	2.74
2	24.7	24.7	24.7	24.7	24.7
3	68.5	68.5	68.5	68.5	68.5
4	134.3	134.3	134.3	134.3	134.3
5	222.1	222.1	222.1	222.1	222.1
CPU (Sec)	N/A	2025	1995	4209	2421

4.2.4 FEER Eigenanalysis Routine

The installation of the FEER eigensolver was completed during 1Q93. The FEER method is a range solver; that is, it extracts a specified number of eigenvalues in a given frequency range. This code, provided by the Air Force, was adapted from that available in the COSMIC NASTRAN program.

Preliminary testing results indicate that this method can result in improved performance for ASTROS problems requiring the extraction of modes. This is primarily due to savings that can

be achieved by eliminating the somewhat costly static condensation that is generally required when using the GIVENS method which extracts all the roots of a system.

The table below compares the CPU times for the available ASTROS eigenextraction methods as applied to the performance test problem PTMODE.

EIGENMETHOD	CPU for Eigenextraction	Total CPU	Notes
GIVENS	**24.4 sec**	**226.2 sec**	Reduced
INVERSE POWER	**69.3 sec**	**90.6 sec**	No reduction
FEER	**44.3 sec**	**65.3 sec**	No reduction

In the case of GIVENS, although the CPU time for the actual eigenextraction is small, the total job CPU is high because of the cost of the reduction procedure. It thus appears that when only some eigenvalues are required, the FEER method will provide a significant computational advantage. This new method is also faster than the inverse power method.

4.3 GRID POINT SEQUENCER

During 1Q91, UAI performed all of the required coding modifications and testing for the Grid Point Sequencer, including changes to the baseline sequencer module which was derived from the BANDIT code used in COSMIC NASTRAN. This important new feature was delivered to COTR in an interim release of ASTROS, designated Version 7.5, in late May 1991.

4.4 CRAY SINGLE-PRECISION PORT

This task, added in, required the full and complete conversion of the standard ASTROS system to function properly on the Cray Y-MP series of computers. This required that every ASTROS subroutine be analyzed to determine the changes required to properly handle conflicting requirements of single and double precision arithmetic. Of particular importance was the handling of dynamic memory pointers.

Work began in 3Q92, when all 1796 ASTROS subroutines were analyzed and it was determined that 387 of these routines had double precision local variables, arguments, or variables in common blocks. Next, for each of these routines it was necessary to manually review every line of code. Then, a decision was made as to the appropriate course of action to be taken. There are two basic approaches to resolving these issues: to create a new subroutine in which all previously double precision variables are changed to single precision; or to include special code within a routine which determines the host machine precision and performs the appropriate operation. The choice of approaches is somewhat subjective, but UAI, in their experience with large software system development, determined that, in general, routines which are primarily computational in nature are recast as two separate versions. On the other hand, routines which are *drivers*, i.e. they set up an environment and then call other routines which perform the actual operations, are generally converted using in-line code.

The next major work item required the review and modification of the matrix utilities including algebraic routines, manipulative routines, and solvers. UAI determined that the most effective manner in which to perform this activity and, at the same time, to increase the robustness of the ASTROS system, was to replace all ASTROS matrix routines with code from UAI's proprietary

UAI/NASTRAN system. These routines have been functioning correctly for many years in the commercial marketplace in both single and double precision versions. (Please note that while UAI *donated* these routines to the benefit of the government, they do not contain all of UAI's proprietary developments. Further, any subsequent maintenance or enhancement is the responsibility of the government under this effort).

All of the modified software was then moved to the Cray-YMP computer in Minneapolis. The system was built and a clean QA performed. Next, the first step of optimization was performed. Shown below is a table comparing computer run time between UAI's MicroVax III and the Cray Y-MP. The first case on the Cray shows the results of the native port, i.e. no compiler optimization, and the second, the results after performing compiler optimization.

Machine	CPU Time (Sec)
DEC MicroVax III	781
Cray Y-MP (No Optimization)	133
Cray Y-MP (Optimization)	64

The conversion task was completed in 4Q94. There were three major areas, described below, that required significant effort under this task.

4.4.1 Problems with MicroDOT Code

The most insidious problem encountered was a numerical instability that occurred in some test cases, most notably the F20 model. The problem was traced to the MicroDOT optimization code. The routines in this module contained a very large number of hard-coded constants, e.g. 10^{-6}, $-1x10^{20}$, $1x10^{-7}$, etc., which appear to have been determined heuristically during the development of this code. These constants were clearly not intended for use on the Cray computer. UAI had to identify all of these situations and analyze their impact on the optimization. A number of changes were made which led to correct results for test cases which previously had erroneous answers.

This exercise pointed out the potential for recurring instabilities for new models which are analyzed and designed with ASTROS. The symptoms will probably be indicated by intermittant failure of jobs to converge. As a result, it may be required to perform more analysis in the MicroDOT module in the future.

4.4.2 Performance Issues

Although this task did not include code optimization for performance on the Cray, it did include the analysis and modification of the machine-dependent library. This library required modifications, some major, in order to bring the Cray performance into the acceptable range. The primary problems encountered were in routines which perform character manipulation. These were corrected and improved.

4.4.3 ICE

The Interactive CADDB Environment, ICE, was also fully implemented on the Cray.

The Cray version of ASTROS was delivered with the Version 10.0 ASTROS system. As discussed above, optimization of ASTROS other than that performed by the Cray compiler was beyond the scope of this task. The final performance measure, comparing the Cray version to UAI's IBM RS6000/560 is presented in the following table.

PERFORMANCE TEST CASE	Cray YMP	IBM/560	SPEEDUP (IBM/CRAY)
ptblst01.d	68	77.5	1.14
ptdesn01.d	66.3	103.3	1.56
ptdesn02.d	49	63.9	1.30
ptdesn03.d	90.3	120.1	1.33
ptdesn04.d	143.0	252.7	1.77
ptfreq01.d	619.0	637.2	1.03
ptfreq02.d	91.2	81.7	0.90
ptgust01.d	80.7	177.7	2.20
ptmode01.d	78.4	101.1	1.29
ptmode02.d	98.4	231.7	2.35
ptmode03.d	44.1	46.4	1.05
ptsaro01.d	144.8	231.1	1.60
ptsaro02.d	58.2	138.6	2.38
ptstat01.d	25.1	27.1	1.08
ptstat02.d	101.1	79.2	0.78
pttran01.d	79.9	90.8	1.14
pttran02.d	102.6	99.7	0.97
ptusar01.d	114.3	208.3	1.82
ptusar02.d	Problem fails on CRAY due to numerical instability		
SUMMARY	2054.4	2768.1	1.35

The range of speedup is 0.78 to 2.38. Optimization of the code to take advantage of the vector power of the Cray could improve this relative performance.

TASK 5. QUALITY ASSURANCE

Under this task, UAI was to perform six subtasks. These are:

Contract Ref.	TASK NUMBER AND DESCRIPTION	Effective Date
3.5.1	5.1 Configuration Management	22SEP87
3.5.1.1	5.1.1 Software Development Plan	22SEP87
3.5.1.2	5.1.2 Configuration Identification	22SEP87
3.5.1.3	5.1.3 Configuration Control	22SEP87
3.5.2	5.2 Testing	22SEP87
3.5.3	5.3 Error Correction	22SEP87

5.1 CONFIGURATION MANAGEMENT

The purpose of Configuration Management is to control the software development process. To accomplish this, three subtasks were performed under this effort. These are described in the following sections.

5.1.1 Software Development Plan

The purpose of this task was to formulate a complete Software Development Plan for the enhancement of ASTROS. The development of this plan began in 3Q87 and was completed in 1Q88. The plan was based on the general requirments and guidelines for software development that are consistent with DOD-STD-2167 and customized for ASTROS. The goal of the plan was to specify the methodology to be used in development of the system to insure quality. A preliminary draft of this plan was delivered to COTR on 9 March 1988.

5.1.2 Configuration Identification

Under this task, UAI identified all of the Computer Software Configuration Items (CSCI) for the ASTROS system. This required the identification of the specific functions of the 825 subroutines that comprised ASTROS at the start of this contract. The CSCI's were defined during 2Q88 and a list of them was provided in the R&D Status Report for that period.

5.1.3 Configuration Control

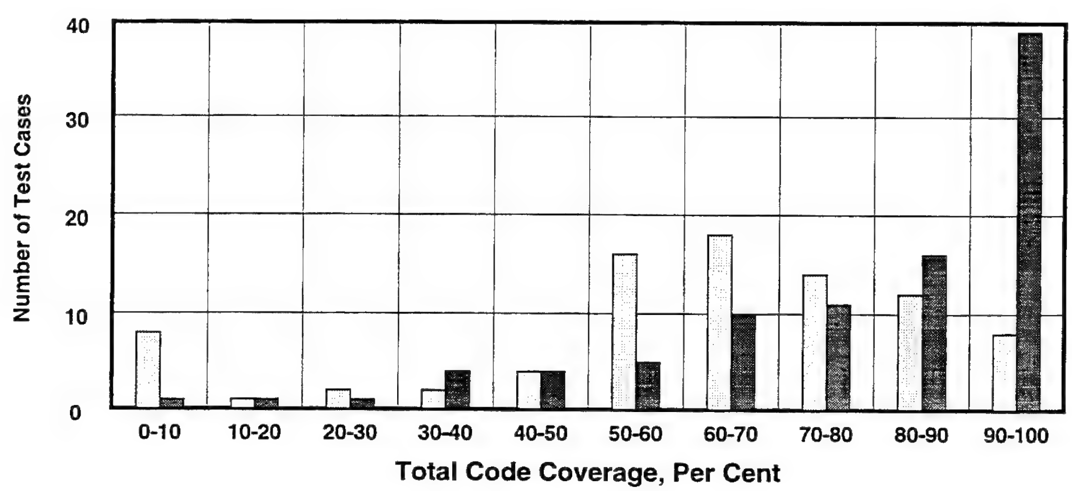
Under this task, UAI used the Source Code Configuration System (SCCS) available on the GFE DEC computer as a configuration management tool. This required the design and implementation of 31 Ultrix script files which were used to perform various development tasks. Such tasks included: retrieving information about CSCI's; comparing different CSCI versions; adding and deleting CSCI items; and building various test systems during a specific development activity. These activities were also accomplished during 2Q88 and a list of the procedures was provided in the R&D Status Report for that period.

5.2 TESTING

The purpose of this task was to perform comprehensive testing of the baseline ASTROS software system and to develop methods to improve such testing. The task began in 2Q88 with the execution of the 63 demonstration problems developed under the original ASTROS contract. UAI executed these using a coverage analysis tool which determines how many times each line of code in a program executes. A list of the results of this testing were presented in the R&D Status Report for this period.

The results of the initial testing indicated that many routines were being inadequately tested. To address this, UAI developed a formal test specification plan as part of the overall Test Problem selection. The intent was to achieve a 90% coverage rate for the entire ASTROS system. During 3Q88, the detailed test plans were formulated for each of the 89 ASTROS CSCI's. These specifications, as well as descriptions of 147 beta test problems. These were delivered to COTR on 10 October 1988 as the ***Beta Test Plan Selection Report*** (CDRL CLIN 0001, Seq. No. 10).

During 4Q88, UAI developed the test problems which satisfy the requirements given in the Beta Test Plan Problem Selection Report. At the end of the reporting period, 167 test cases had been developed and executed using ASTROS Version 2. Detailed coverage data was maintained. The chart below compares the current coverage levels of these problems to that of the original 64 problems used for QA testing of the system.



Total system coverage for this test suite, not including any of the original test problems, now exceeds 70%.

UAI continued the development and execution of the test problems specified in the Beta Test Plan Problem Selection Report during 1Q89 and 2Q89, at which point total system coverage for this test suite, not including any of the original test problems, exceeded 83%. Additional test problems have been developed to cover the new and modified capabilities reported in the other sections of this report.

During 3Q89, UAI completed the prototype of the automated QA program suitable for the regression testing of future releases of ASTROS.

5.3 ERROR CORRECTION

Under this task, UAI corrected errors in the ASTROS software, including those reported by external user's, and those discovered during testing under 5.2 above. In addition to correcting errors, UAI developed an ***Error Log*** which has been distributed to the current user community since ASTROS Version 3. This log includes the descriptions of the errors that have been reported and, where possible, the manner in which a user may avoid them.

This task, which lasted for the duration of the contract effort, resulted in the correction of many hundreds of errors. The details of many of these were included in R&D Status Reports, and are too voluminous to repeat here.

TASK 6. POST-PROCESSOR INTERFACES

Under this task, UAI was to perform six subtasks. These are:

Contract Ref.	TASK NUMBER AND DESCRIPTION	Effective Date
3.6.1	6.1 OFP Interfaces	22SEP87
3.6.1.1	6.1.1 New Output Data	22SEP87
3.6.1.2	6.1.2 New Bulk Data	22SEP87
3.6.2	6.2 CADDB Interface	22SEP87

6.1 OFP INTERFACES

Under this task, UAI made modifications and enhancements to the OFP module and related Solution Control directives in two areas. First, the range of data that can be selected for output to a punch file was enlarged. Second, the option to generate a new Bulk Data deck was implemented.

6.1.1 New Output Data

Under this subtask, Northrop and UAI modified ASTROS so that a user can direct additional data to a punch file. All of these additions were made during 3Q90 and 4Q90, and they were released in Version 7.0 of ASTROS in February 1991.

6.1.2 New Bulk Data

Under this task, UAI added a new capability to OFP for the user to direct the generation of new Bulk Data deck which represents the design found by ASTROS during any cycle of optimization. This feature, which allows a new data file to be created from any design iteration, was released in Version 9.0 of ASTROS in August, 1992.

6.2 CADDB Interface

Under this task, UAI developed the Interactive CADDB Interface (ICE). This separate interactive program was designed to allow the ASTROS CADDB database to be queried by users. The language selected was the Structured Query Language, SQL, which is the standard interface to relational databases. Work on this task began before the arrival of the GFE computer. During 1Q88 all design specification documents and the Critical Design Review were complete. The preliminary draft of the Ice User's Manual was delivered to COTR on 8 March 1988.

The first version of ICE was completed during 2Q88 and demonstrated to the WL team at the Quarterly Review held on 23 June 1988 at WPAFB. The ICE Interface was completed during 3Q88 and delivered to COTR along with the ICE User's Manual, which was reviewed and published as AFWAL-TR-88-3060. ICE was officially released in Version 3.0 of ASTROS in January 1989.

SEMI-ANNUAL REVIEWS

The following table summarizes the semi-annual contract reviews that were held, and participation in other ASTROS-related activities, during the contract effort.

REVIEW/ ACTION	LOCATION/DESCRIPTION	DATE
INITIAL	CONTRACT SIGNED	22SEP87
KICKOFF	WPAFB	21OCT87
1	WPAFB	23JUN88
2	WPAFB	4NOV88
3	WPAFB	18MAY89
4	WPAFB	06FEB90
5	WPAFB	26JUL90
6	WPAFB	21FEB91
—	ASTROS Training Course, Cray Research	JUN91
—	ASTROS Training Course, Phillips Laboratory (CA)	FEB92
—	ASTROS Training Course, WPAFB	FEB93
Informal	Meeting at SDM, La Jolla, CA	20APR93
—	ASTROS Training Course, Georgia Tech	16MAY94
—	ASTROS Training Course, WPAFB	08AUG94
—	ASTROS User Group Meeting (FL)	SEP94

CDRL ITEMS

The following chart summarizes the Contract Data Requirements List (CRDL) items for the contract effort. Note that CDRL Seq. Nos. from 1 through 7 are standard Quarterly Reports and other contract information. The following table summarizes those items which represent contract deliverables.

CLIN	CDRL Seq. No.	DESCRIPTION	DATE
0001	8	ASTROS Enhancements Software Development Plan	03NOV88
0001	9	Timing Analysis Problem Selection Report	02SEP88
0001	10	Beta Test Problem Selection Report	10OCT88
0001	11	Software Theoretical Manual	16JUN95
0001	12	Software Programmer's Manual	04JUN93
0001	13	Software User's Manual	13MAY93
0001	14	Final Report	16JUN95
0001	15	Software Programmer's Manual (Revised)	16JUN95
0001	16	Software User's Manual (Revised)	16JUN95
0002	1	Computer Software Product	See Next Section
0002	2	Interactive CADDB Interface	10OCT88

ASTROS SYSTEM RELEASE

Over the course of the ASTROS Enhancements contract effort, UAI generated 13 releases of the software. Eleven of these were general releases, and two were special releases which were requested by COTR. The following table provides a summary of these systems and a brief description of their technical highlights.

VERSION	RELEASE DATE	HIGHLIGHTS
2	JUN88	First UAI release after Configuration Management implementation.
3	JAN89	Release of the Interactive CADDB Enivironment and major changes to design variable linking and constraint definition.
4	JUN89	Version 4 included the TRIA3 element and the correction of known problems in the QUAD4 element. Additionally, the two new eigenextraction methods were released and the Generalized Dynamic Reduction (GDR) feature was improved. A new document, called *ASTROS System Release Notes*, was introduced with this release. These notes provide a vehicle for disseminating information to the user community describing the highlights of the new version and providing interim user documentation modifications.
5	FEB90	The key features for Version 5 were the aeroelastic improvements performed by UAI's subcontractor Northrop.
6	JUL90	New rigid elements, aeroelastic constraints, and a new CEAD module for complex eigen analysis.
7	FEB91	New OFP Interfaces, Optimality Criteria methods, and the Grid Point Weight Generator.
7.5	MAY91	This was an interim system that included a pre-release of the Grid point sequencer.
8	AUG91	Final version of the Grid point sequencer and completely redesign stress/strain design constraints.
9	AUG92	New Bulk Data punch feature and Grid point force output.
10	JUN93	New FEER eigenanalysis method, laminate constraints, rigid body strain energy checks, and the release of the CRAY UNICOS version.
10.5	SEP93	Error corrections and prerelease of AUTOSPC feature at the special request of COTR to support the HSCT program.
11	MAY94	Key features included AUTOSPC and the panel and column buckling capabilities.
12	JUN95	Final developments including bending sensitivities and user defined objective and constraint functions.

CONTRACT MODIFICATIONS

During the course of this effort, the were two major contract modifications. These are summarized in the following sections.

First Redirection of Effort

On 22 June 1989, UAI received a formal request from the Contracting Officer, to offer a proposal to the Air Force for modifying the current contractual effort. The Air Force wished to modify Task 3, Optimality Criteria, due to the potential availabilty of GFP, such that additional effort could be expended on Task 1, Finite Element Library, and Task 2, Aeroelasticity. UAI responded to this request on 1 July 1989.

On 1 September 1989, UAI received a summary of the changes proposed by the Air Force for this modification. After several iterations, UAI received a Redirection of Effort and Extension of Performance Period on 28 September 1990, This change added three new tasks to the contract effort:

- Task 3.1 Generalized Stiffness Constraint
- Task 3.2 Stress/Strain Constraints
- Task 4.3 Grid Point Sequencer

and extended Task 5.3, Error Correction. Addtionally, delivery dates for CDRL items were modified.

Second Redirection of Effort

On 9 September 1992, UAI received a Redirection of Effort and Change of Performance Period. This change added eight new tasks to the effort:

- Task 1.5 Automatic SPC Generator
- Task 2.11 FFT With Random Input
- Task 3.3 Bending Element Sensitivity
- Task 3.4 Buckling Optimization
- Task 3.5 User-defined Constraint and Objective Functions
- Task 3.6 Composite Laminate Constraints
- Task 4.2.4 FEER Eigenvalue Analysis
- Task 4.3 Cray Single Precision Port

In addition, Task 5.3 Error Correction was extended for the duration of the new effort.